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Physics Procedia 33 (2012) 1280 – 1285

Physics Procedia

2012 International Conference on Medical Physics and Biomedical Engineering

Simulation and Research of Control-System for PMSM Based on Sliding Mode Control

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Abstract

In this paper, permanent magnet synchronous motor rotor flux oriented control strategy is studied, for the key issues of vector control is to observe the rotor flux, the control system is given based on sliding mode observer, and the sliding mode rotor flux observer is designed, with MATLAB/SIMULINK simulation, the results of simulation show that the system with wide speed range, has a good dynamic and static performance.

Keywords: Permanent magnet synchronous motor. Simulation. Sliding mode flux observer.

1.Introduction

Permanent magnet synchronous motor with permanent magnets replaces the electrical excitation system, and eliminates the need for field winding, collecting ring and brush. And, the stator is identical with electrical excitation three-phase synchronous motor. Voltage space vector SVPWM control technique, which can convert the DC voltage into a pulse sequence, using turn-on and turn-off of semiconductor switching device, and can achieve the purpose of the frequency conversion, voltage regulation and reduce the harmonic content by controlling the voltage pulse width or cycle, is a control technology. The purpose of SVPWM control is to reasonably combine the 8 basic voltage space vectors by a combination of switch state, and to make the synthesis of voltage space vector Ur rotate in circular in the light of the given reference value, and the rotating trajectory of flux space vector is more approximately round by controlling the role time of the basic voltage space vector, and to achieve the best control technology [1].

Observed motor rotor flux can be detected through indirect or direct detection methods. Because there are noise and error in the measurement, the value of the direct measurement has a large deviation. Usually

 doi:10.1016/j.phpro.2012.05.211

we don't adopt direct detection flux observations, in order to ensure accurate and reliable determination of internal state, indirect detection method is able to reduce these errors. Indirect detection methods are the use of motor voltage, current or speed signal, according to some algorithm, constitute a flux observer. Flux observer is the widest research method of indirect flux detection. In this paper, the rotor flux information can be observed with the sliding mode observer.

2.Sliding Mode Control

Sliding mode control is a special class of nonlinear control. The difference between this control strategy and other control is that the "structure" of system is not fixed, but can be in a dynamic process, meanwhile it is purposefully constantly changing according to the current state of the system (such as bias and deviation of the first derivative, etc.), forcing the system to move in accordance with the state trajectory of the expected "sliding mode," so the variable structure control is often called sliding mode control, and short of sliding mode control [2].

Because the motor control system needs to adjust the size of rotor flux in certain moments, and needs some special modules to analyze the state of motor rotor flux, so as to prepare the follow-up of the control process. Whether the rotor flux can be accurately observed or not, directly affects the accuracy of the control system. Analysis shows that: If the flux phase observations are accurate, and flux observation arrangement is not accurate, this will make situation: when the flux amplitude should be increased, it will reduce; or when the flux amplitude should decrease, it will increase. The former situation will lead to reduce motor output torque, and may make motor not run; the latter case will result in air-gap magnetic saturation, the stator current waveform distortion, large torque output. The two exceptions would lead to increase torque ripple, speed fluctuations, and affect the operating characteristics of steady state of the system.

Rotor flux observation by indirect or direct detection methods is detected. Because there are noise and error in measurement, so the value of the direct measurement has a large deviation. The direct measurement is not usually carried out to observe flux, in order to ensure accurate and reliable determination of internal state, and indirect detection method is able to reduce these errors. Indirect detection methods are the use of motor voltage, current or speed signal, according to some algorithm, constitute a flux observer. Flux observer is the most widely studied Flux Detection. In this paper, the rotor flux information can be observed with the sliding mode observer [3].

In the α-β stator stationary coordinates system, the mathematical model of PMSM can be expressed as:

$$\begin{cases} \frac{di_\alpha}{dt} = -\frac{R}{L} i_\alpha - \frac{1}{L} e_\alpha + \frac{u_\alpha}{L} \\ \frac{di_\beta}{dt} = -\frac{R}{L} i_\beta - \frac{1}{L} e_\beta + \frac{u_\beta}{L} \\ e_\alpha = -\psi_f \omega_r \sin\theta_e \\ e_\beta = -\psi_f \omega_r \cos\theta_e \end{cases}$$

. When the motor is running stable, $\dot{\omega} \approx 0$, can be derived,

$$\begin{cases} \dot{e}_\alpha = -\omega_r e_\beta \\ \dot{e}_\beta = \omega_r e_\alpha \end{cases}$$

, Sliding mode observer system equations of the form $\frac{dx}{dt} = A(x) + B(x) \cdot u$ The motor voltage equation is expressed as [4]:

$$\begin{bmatrix} \frac{di_\alpha}{dt} \\ \frac{di_\beta}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R_r}{L_d} & -\frac{\omega_r(L_d - L_q)}{L_d} \\ \frac{\omega_r(L_d - L_q)}{L_d} & -\frac{R_r}{L_d} \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} + \begin{bmatrix} \frac{1}{L_d} & 0 \\ 0 & \frac{1}{L_d} \end{bmatrix} \begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} + \begin{bmatrix} -\frac{1}{L_d} & 0 \\ 0 & -\frac{1}{L_d} \end{bmatrix} \begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} \quad (1)$$

Can also be abbreviated as: $\frac{di_s}{dt} = A(i_s) + B(u_s) + K_e e_0$, $\begin{bmatrix} -\frac{1}{L_d} & 0 \\ 0 & -\frac{1}{L_d} \end{bmatrix} \begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix}$ This part is the αβ two phase stator stationary coordinate system extended EMF, The system can use the following combination of sliding mode observer, $\frac{d\hat{i}_s}{dt} = A(\hat{i}_s) + B(u) - \frac{K}{L_s}\operatorname{sgn}(\hat{i}_s - i_s)$ (2)

In the formula, $\hat{i}_s$ is observations, K is the observer switching gain, $\operatorname{sgn}(\hat{i}_s - i_s) = \begin{cases} 1 & \hat{i}_s - i_s \rangle 0 \\ -1 & \hat{i}_s - i_s \langle 0 \end{cases}$, Formula (2) minus equation (1) obtains the dynamic equation estimated current error:

$$\frac{d\hat{i}_s}{dt} = A\hat{i}_s - K_s e_s - \frac{K}{L_s}\operatorname{sgn}(\hat{i}_s - i_s) \quad (3)$$

Equation (3) can be expressed as components of the form:

$$\begin{cases} d\bar{i}_\alpha = -\frac{R_1}{L_d}\bar{i}_\alpha - \frac{\omega_r(L_d - L_q)}{L_d}\bar{i}_\beta + \frac{1}{L_d}e_\alpha - \frac{K_1}{L_d}sign(\bar{i}_\alpha) \\ d\bar{i}_\beta = -\frac{R_1}{L_d}\bar{i}_\beta + \frac{\omega_r(L_d - L_q)}{L_d}\bar{i}_\alpha + \frac{1}{L_d}e_\beta - \frac{K_1}{L_d}sign(\bar{i}_\beta) \end{cases} \quad (4)$$

In the above formula, $\bar{i}_\alpha = \hat{i}_\alpha - i_\alpha, \bar{i}_\beta = \hat{i}_\beta - i_\beta$ is the observation error, when the state point reached the hyperplane, $\bar{i}_s = \frac{d\bar{i}_s}{dt} = 0$, this time, the performance of the error dynamic equation (4) is entirely determined by the sliding mode motion, then there is the equivalent of the continuous signal $\begin{cases} e_\alpha\big|_{eq} = (K_1 \operatorname{sgn} \bar{i}_\alpha)_{eq} \\ e_\beta\big|_{eq} = (K_1 \operatorname{sgn} \bar{i}_\beta)_{eq} \end{cases}$, After the sliding movement to reach stable points, $e_\alpha\big|_{eq} = \hat{e}_\alpha$, $e_\beta\big|_{eq} = \hat{e}_\beta$

EMF estimate derived $\hat{e}_\alpha$, $\hat{e}_\beta$, have the formula, $\begin{cases} e_\alpha = -\psi_f \omega_r \sin\theta \\ e_\beta = \psi_f \omega_r \cos\theta \end{cases}$, Observations of the magnetic flux can be made: $\psi_f = \sqrt{\dfrac{e_\alpha^2 + e_\beta^2}{\omega_r}}$.

Combination of sliding mode observer, this according to the characteristics of permanent magnet synchronous motor, In this article, the vector control system based on sliding mode flux observer was designed.

In Matlab's Simulink environment, using its powerful module, built a simulation model. System mainly consists of phase current detection part of the judge, rotor position detection and speed detection, speed and current PI control section, part of the rotor flux observer, In addition, the system also includes vector in the transformation between different coordinate system, and part of the space voltage vector PWM signal generation and logic decision.

3.Control Process Analysis

This system adopts the hysteresis current control in order to fast and accurately control the stator current vector. The speed closed-loop control is situated on the outer ring of the control structure, in order to make the motor well follow the given speed. Inner hysteresis PWM current control is the core of the structure, in order to fast track the current signal. Power electronic switching devices adopt IGBT devices. DC side uses irreversible three-phase full-bridge rectifier and two capacitors in series regulator. Motor speed is detected by optical encoder means, and current is detected by Hall element current sensor [5].

When the system is stably running, cross-axis current command first by anti-rotation transformation and 2 / 3 transform, obtained ABC phase stator current target. These currents are three-phase sinusoidal current which have equal amplitude, each phase 120 ° difference. through Hall sensors get the two-phase current, then ask another phase current, after this ,input the three-phase stator current actual value and target value to the hysteresis comparator, then the hysteresis output generated PWM signal to drive motor work.

In this system, the speed of the input reference, the current voltage and speed these three factors decide whether to change the Value of rotor flux or not. Obtained voltage and phase current motor by the detection circuit, through coordinate transformation into coordinate system voltage and current, and then passed to the sliding mode flux observer, to estimate the rotor flux current value. This value is as a reference of the impulse magnetic logic judge module to make decision. In this decision, you need to know the value of stator voltage. If the stator voltage has reached or close to the value of DC bus voltage Udc, it indicates need to weaken the rotor flux if increase the bus voltage utilization. If the motor speed decreases to a certain extent, the torque need to increase, the rotor flux value should be increased to enhance the capacity of motor with load. At the same time, the current value of the rotor flux also has another role, that is, it shows how much the current flux can be used to alter the operating performance. If magnetic flux density of the motor positive and negative directions magnetizing have greater difference, it shows that memory motor changing the electrical properties through magnetization are larger. In addition, setting magnetizing current needs to know position of the permanent magnet motor working point on demagnetization curve, only in the way can set the magnetizing current value [6]. If in the actual magnetizing process of cross-axis current is large, then the inverter cannot provide enough current to magnetizing operation. Therefore, when motor establish magnetizing MMF, cross-axis current need reduce to zero, so as to provide more headroom for direct axis magnetic motive force.

4.Simulation Results

Motor parameters are as follows: Rated power PN = 3000kW rated speed n = 1000r/min rated current I = 6.5A rated voltage U = 380V stator resistance R = 2.975Ω axis inductance LD = 45mH cross-axis inductance Lq = 60mH rotor pole pairs P = 3 rotor Wing magnetic flux Ψf = 0.8Wb

Simulation result, the motor speed from zero speed to 1000r/min rated speed, the actual value of the sliding mode flux observer and the value of the estimated rotor flux is not greatly, the actual value and the estimates bias on small scales within, In a relatively short time, it can track the estimated flux value, as shown in Figure 1. Initially, the speed curve rapidly increases, when it reaches up to near the ratings, it tends to the steady soon, as shown in Figure 2.

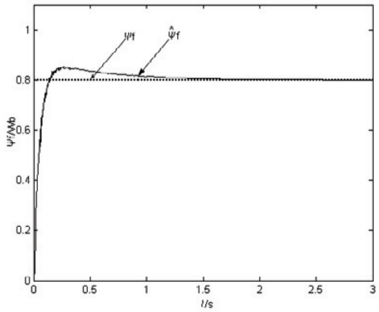


Fig. 1 Observing results of the rotor flux

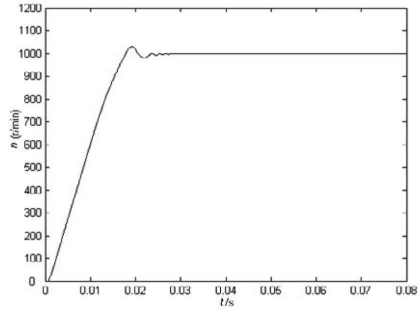
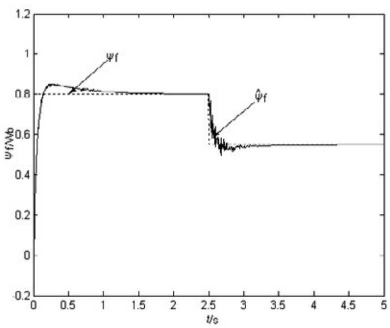


Fig. 2 Speed curve

When the motor rotates increased to the high-speed 1500r/min from the rated speed 1000r/min, the logic decision module of the direct axis pulse current id, combined with target speed, current speed, and PM flux linkage values ,sends the magnetic pulse current id at t = 2.5s. The magnetic pulse current id changes the working status of the permanent magnet; the situation of the sliding mode flux observer tracking magnet flux is shown in Figure 3, and the speed response to the magnetic control is shown in Figure 4.



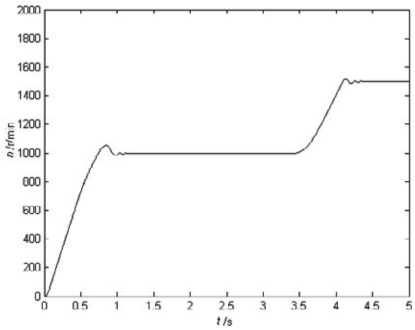


Fig. 3 The flux observation of demagnetization control before and after

Fig. 4 The speed response of demagnetization control before and after

As can be seen from Figure 3, the estimated value of flux (shown as dotted line) at t = 2.5s, has a Step change, then the actual value of flux values (truthfully line) can achieve the desired goals in a relatively short period of time, and complete the task of demagnetization.

As can be seen from Figure 4, when demagnetization had a Step change at t = 2.5s, the speed did not changed, after, under the action of the magnetic, the speed gradually increased, and changed significantly, when demagnetization basically completed at t = 4s, the speed up to 1500r/min, then gradually tended to steady.

5.Conclusion

The simulation results show that, in this paper, the permanent magnet flux observer based on sliding mode control, can better estimate the rotor flux of permanent magnet synchronous motor, and the accuracy of the estimation is higher. The vector control system based on Flux observer can adjust the speed of the permanent magnet synchronous motor in a wide range; this sliding mode observer based on control system has a good static and a dynamic performance.

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